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FORECASTING RAINFALL FOR THE SUMMER SEASON IN ENGLAND AND WALES

By R. A. S. RATCLIFFE and P. COLLISON

Summary. Changes in the average spacing, at 50°N, between the Canadian and European troughs on monthly mean 500-mb contour charts from April to summer are analysed. From this analysis some rules for forecasting the total amount of rainfall over England and Wales in summer are developed. The number of years (22) for which monthly mean 500-mb charts are available is not sufficient to give confidence in the stability of any rules developed solely from such a small sample; the 22 years have been supplemented therefore by 41 years (1899–1939) for which monthly mean 500-mb charts have recently been constructed using a statistical method developed in the Synoptic Climatology branch of the Meteorological Office. Generally the results show significant success as an aid in forecasting summer rainfall.

Introduction. Hay[1] has shown that monthly mean temperature anomalies over Europe and the North American continent in April have some value in the prediction of rainfall for the following summer (June, July and August) over England and Wales. Since monthly mean 500-mb contour charts take account of both mean surface pressure and mean 1000 to 500-mb thickness it was felt that such charts might be an even better guide to forecasting summer rainfall. Monthly mean 500-mb charts are available for the years 1946 – 67 inclusive. Daily values of surface pressure for grid points in the northern hemisphere for the period 1899 – 1939 have been obtained recently on magnetic tape from American sources. This data has enabled 'fictitious' monthly mean 500-mb charts to be constructed by computer for the 41 years covered by the data. It is not intended here to describe in detail the method of construction of these charts but the following brief account may be of interest.

Every monthly mean 500-mb chart can be constructed from two components, the normal 500-mb chart (in this case for 1951 - 66) and the 500-mb anomaly chart for the month in question. In our method the 500-mb anomaly was obtained for each grid point of each April chart by carrying out certain transformations on the April surface pressure anomaly for each year (again based on the 1951–66 normal). The transformations were selected to give the best possible approximation to the total 500-mb anomaly in the years 1951–66, for which actual charts are available for comparison, and then the method was applied to the earlier years for which surface pressure anomalies could be obtained but no 500-mb data existed. The transformations consisted of two parts :

(i) Production of 1000-mb anomalies at each grid point, based on the surface pressure and temperature at the grid point.

(ii) Production of an estimated 1000 to 500-mb thickness anomaly at each grid point, based on the surface pressure anomaly field in the vicinity of the grid point.

The two factors together comprised the best estimate of the 500-mb anomaly field for each April and they were added to the 500-mb normal at each grid point, by computer, to produce a best estimate of the 500-mb chart for April of each year. In the end the method adopted gave a standard deviation of rather over 30 metres for each grid point when real and fictitious charts were compared.

This paper presents the results obtained from a study of the 22 years of actual 500-mb data supplemented by the 41 years of 'fictitious' data. Results from the two sources are in good general agreement.

Mean 500-mb wavelengths. A study of the average spacing between the Canadian and European troughs on monthly mean 500-mb charts was made recently. How this spacing varies over the year was illustrated in the first Figure of a recent paper by Ratcliffe.[2] He showed that the average spacing between the troughs (measured at 50°N) changes from about 80 degrees of longitude in April to a mean of about 65 degrees of longitude for much of the summer (June, July and August).

In order to ascertain in more detail how this shortening of mean wavelength between April and summer comes about, it was decided to study the variability of the Canadian and European trough longitudes between April and the following summer. This was done by using computer-produced mean charts for each summer in the period 1949 – 67, the only years for which data were available in a suitable form, and comparing them with the 500-mb charts for April in the same years. The results obtained for the Canadian and European troughs are presented in Tables I and II respectively.

TABLE I—CHANGE IN LONGITUDE OF CANADIAN 500-MILLIBAR TROUGH AT 50°N BETWEEN APRIL AND SUMMER

Year	Longitude in April °*W*	Mean longitude in summer °*W*	*Change in longitude *degrees*
1949	65	50	+15
1950	75	75	0
1951	75 to 80	70 to 75	+ 5
1952	65	70	− 5
1953	75	65	+10
1954	60	65	− 5
1955	50	55	− 5
1956	70 to 75	60 to 65	+10
1957	55	60	− 5
1958	65	65	0
1959	75	55	+20
1960	55	65 to 70	− 10 to − 15
1961	50	65	−15
1962	60	65	− 5
1963	55	60 to 65	− 5 to − 10
1964	60	65	− 5
1965	60	70	−10
1966	40	65	−25
1967	60	75	−15
Approximate mean	62	65	− 3

*Standard deviation approximately 10 degrees

TABLE II—CHANGE IN LONGITUDE OF THE EUROPEAN 500-MILLIBAR TROUGH AT 50°N BETWEEN APRIL AND SUMMER

Year	Longitude in April *degrees*	Mean longitude in summer *degrees*	*Change in longitude *degrees*
1949	40 to 45 E	20 to 25 E	−20
1950	5 E	20 W	−25
1951	5 to 10 E	10 to 15 W	−20
1952	45 E	Doubtful	
1953	5 W	0	+ 5
1954	30 E	0	−30
1955	25 E	30 E	+ 5
1956	15 E	0	−15
1957	15 to 20 E	0	−15
1958	15 E	10 W	−25
1959	10 W	Doubtful	
1960	20 E	10 W	−30
1961	40 to 45 E	20 E	−20 to −25
1962	10 E	0	−10
1963	30 E	5 W	−35
1964	5 W	5 W	+ 0
1965	20 to 25 E	0 to 5 W	−25
1966	20 E	0 to 5 W	−20 to −25
1967	10 E	10 W	−20
Approximate mean	18 E	0	−18

*Standard deviation approximately 11 degrees

Thus we see that on the average the shortening of mean wavelength takes place mainly through retrogression of the European trough from a mean April position of 18°E to a mean summer position near the Greenwich meridian. Nevertheless, individual years show considerable differences, as indicated in Tables I and II and extreme positions of the European trough in April vary through about 60 degrees of longitude from 15°W to about 45°E.

Development of forecasting rules. Figure 1, which shows the variation between the longitude of the European trough in April at 50°N and the rainfall over England and Wales for the following summer, was next plotted. The points on the figure are for all 63 years of the real and fictitious series except 1928 for which no European trough in April was detectable. The horizontal lines at 9.95 and 7.55 inches indicate the long period (90 year) tercile boundaries for England and Wales rainfall in summer.* Although there is a wide scatter of points on the graph a few facts can be deduced, of which the following seem important :

(i) Of the 20 years with wet summers, 13 have their 500-mb European troughs in April in the longitude range >10°E to <30°E. If the band is narrowed to include only the range >10°E to <25°E then 9 wet years are still included while the only dry year out of a total of 14 years is 1929. The figures for the real charts in this latter band are 5 wet years (out of a total of 8) and no dry years.

* Rainfall amounts in this paper have been quoted in inches as the data for England and Wales are available to the nearest 0·1 inch. The tercile boundaries are quoted to the nearest 0·05 inch (and the nearest millimetre) to achieve separation of the data groups. Figure 1 incorporates scales for inches and millimetres.

(ii) In the two bands *(a)* westwards from 10°E and *(b)* eastwards from 30°E, out of a total of 43 years only 7 have wet summers and 3 of these (1909, 1910 and 1930) are only just in the wet tercile. For the real charts in these bands the figures are 2 wet summers in 14 years.

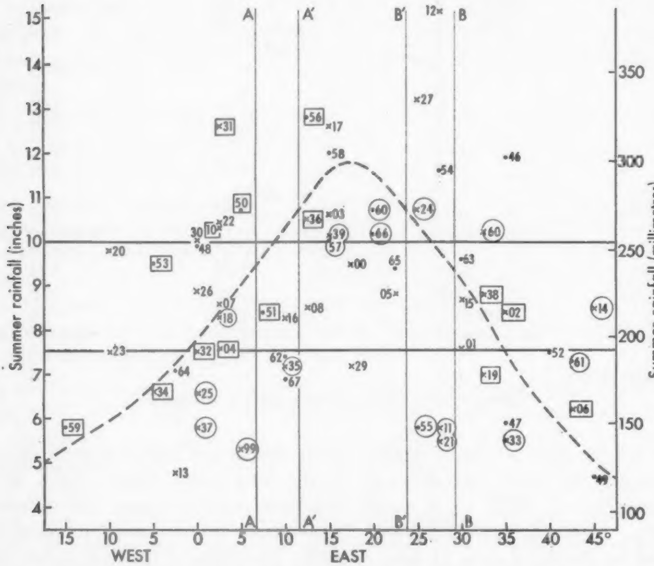

FIGURE 1—RELATIONSHIP BETWEEN SUMMER RAINFALL OVER ENGLAND AND WALES, AND LONGITUDE OF EUROPEAN TROUGH AT 50°N IN APRIL

Full lines are tercile boundaries of summer rainfall. AA′ and BB′ are areas of uncertainty. Figures represent the year, omitting the century. Dots for post-war data 1946–67 and crosses for fictitious constructed data 1899–1939. Figures are enclosed in circles when the Canadian trough was east of normal position, and enclosed in squares when the Canadian trough was west of normal position.

It has been shown by Lowndes[3] that fine weather in summer in south-east England is usually associated with a 500-mb trough between 50°W and 60°W on a day-to-day basis. Ratcliffe[2] has also associated dry summer weather on a monthly time scale with 500-mb troughs east of the normal summer position (65°W) and wet summer weather with troughs west of 65°W. Thus it was considered possible that a Canadian trough in April east of its normal position might be associated with drier than normal summer weather to follow and if west of normal it might be associated with a wet summer.

A graph similar to Figure 1 was constructed, therefore, to show the relationship between the position of the Canadian trough in April and summer rainfall in England and Wales but this is not reproduced because the scatter is very large and no precise deductions can be made from it. Nevertheless, for all summers during which the Canadian trough was east of normal in April the average rainfall was 8·0 inches, while for all those with troughs west of normal the average rainfall was 9·0 inches. The real 500-mb data for the 22 post-war years shows the same trend (8·5 against

Photograph by W. H. Townsend

PLATE I—OROGRAPHIC CLOUD (MULTI-LAYERED WAVE CLOUDS) FORMED IN AIRFLOW OVER MOUNTAINS OF GRAHAM LAND

The photograph was taken in September 1961 from Argentine Island (approx. 65°S and 65°W) with the camera looking NE. This picture won the first prize for Mr W. H. Townsend in the black and white section of the Meteorological Office Photographic Competition in 1967.

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Photograph by D. McFarlane

PLATE II—STRATOCUMULUS FROM ABOVE, SHOWING BILLOWS

The photograph was taken from 10 000 ft with camera looking east-north-east at 1505 GMT near Preston, Lancashire, 14 December 1967. The height of the cloud has been estimated as 3000 ft.

8·9 inches). Thus it is clear from Figure 1 that the position of the European trough in April is more important than that of the Canadian one from the point of view of wetness or dryness of the following summer. A curve of best fit was drawn through the points of Figure 1, leaving approximately the same number of points above and below the curve. It is seen that the rainfall curve shows a peak with European 500-mb troughs between 15 and 20°E in April. Bearing in mind that the average April to summer retrogression is nearly 20° of longitude (from Table II) it is easy to see that in such years the mean summer position of the 500-mb trough is likely to be near the Greenwich meridian — a position which is probably the optimum for copious summer rain. It is relevant to note that the points for most of the years in which the Canadian trough was east of 60°W (within circles in Figure 1) lie under the curve, i.e. summers drier than expected, while most of those in which the Canadian trough was west of 65°W (within squares in Figure 1) lie above the curve, i.e. summers wetter than expected.

Thus it appears that Figure 1 could be used as a forecasting tool for summer rainfall if a correction were applied for the position of the Canadian trough in April. The amount of correction applied is given in Table III.

TABLE III—CORRECTIONS TO SUMMER RAINFALL FORECASTS TO TAKE ACCOUNT OF LONGITUDE OF CANADIAN 500-MILLIBAR TROUGH AT 50°N IN APRIL

Longitude of trough	(°W)	75	70	65	60	55	50
Correction to rainfall	(inches)	+1	+½	0	0	−½	−1

This table was deduced from the following : (i) normal summer rainfall is about 8·8 in over England and Wales, (ii) the normal Canadian trough position in April is about 62°W; together with the previously noted fact that summers of years with Canadian troughs west of normal in April gave an average rainfall of 9·0 in, while those with troughs east of normal averaged 8·0 in.

The use of Figure 1 with corrections from Table III to obtain forecasts of summer rainfall in terms of terciles, gives the results shown in Table IV.

TABLE IV—RELATIONSHIP BETWEEN THE ACTUAL SUMMER RAINFALL IN ENGLAND AND WALES AND THE FORECAST RAINFALL

		Forecast summer rainfall			
		Wet	Normal	Dry	Notes
Actual summer rainfall	Wet	11(5)	8(2)	0(0)	The figures in brackets are post-war real data.
	Normal	5(2)	8(1)	5(1)	$\chi^2 = 16{\cdot}6$ significant at the 0·5 per cent level.
	Dry	4(2)	6(1)	12(5)	

It may be that an analysis such as Table IV attempts to deduce too much from the type of data available. It may be safer to consider Figure 1 as made up of three bands separated by areas of uncertainty AA′ and BB′. If this is done the results in terms of terciles are as follows :

		Actual summer rainfall		
		Dry	Normal	Wet
(i)	Years west of AA	9(2)	8(2)	5(1)
(ii)	Years east of BB	7(4)	6(1)	2(1)
	Total of (i) and (ii)	16(6)	14(3)	7(2)
(iii)	Years between A′A′ and B′B′	1(0)	4(1)	9(5)

(Brackets enclose real data only)

It is logical to consider AA′ and BB′ as areas of uncertainty when the rather large variability of the retrogression of the European 500-mb trough between April and summer is considered. For example although retrogression averages 18° of longitude (see Table II), in 1955 the trough progressed 5° while in 1954 the retrogression was 30°. Although no wet years actually occur in the longitude band between A and A′ this is regarded as fortuitous as similar possibilities to those observed in the range B to B′ could occur.

The safest statements based solely on the longitude of the European 500-mb trough at 50°N in April would be :

(i) If the trough is at 30°E or further east *or* at 5°E or further west — forecast dry or normal. (Correct 30 times out of 37.)

(ii) If the trough is east of 10°E and west of 25°E — forecast wet or normal. (Correct 13 times out of 14.)

Discussion. Results such as these lead one to question why the position of 500-mb troughs in April should apparently be so crucial for summer rainfall. The answer is probably very complex but it is believed to be connected with the nature of the underlying land surface. If snow cover in Canada near or west of Hudson's Bay is still deep in April this is likely to have some effect on the Canadian 500-mb trough, tending to hold it west of normal and hence tending to prolong the delay in seasonal warm-up of the land surface in that area. Similar considerations could apply in Europe ; if in April there is deep snow as far west as possible this may tend to hold the European 500-mb trough at about 10° – 30°E until the normal shortening of wavelength (mainly in May) takes place. On such occasions the European trough, undergoing the expected 20° of retrogression, will settle near the British Isles for the summer. Similar arguments could be applied in reverse ; the absence or reduction of snow cover in central Canada coupled with a snow-free Europe in April would allow the Canadian trough to occupy an eastern position and the European trough to recede into Russia thus enhancing the probability that the European trough would not retrogress as far as the British Isles in summer.

Conclusions. It is shown that the mean position of the European 500-mb trough at 50°N in April is almost 20°E and that the corresponding mean position averaged over the whole summer is close to the Greenwich meridian. In contrast the Canadian 500-mb trough retrogresses only about 3° during the same period.

A correlation between the position of the European 500-mb trough in April and summer rainfall in England and Wales is demonstrated; the wettest summers in general follow April 500-mb troughs between 10° and 30°E while most dry summers are preceded by April 500-mb troughs east of 30°E or west of 10°E.

When the Canadian 500-mb trough in April is displaced eastwards from its normal position near 62°W, the summers following are drier than usual while if the Canadian trough is displaced westwards (not beyond 75°W), the summers following are wetter than expected. These additional factors have been taken into account in deriving forecasting rules for summer rainfall in England and Wales.

REFERENCES

1. HAY, R. F. M.; Spring temperature-anomalies and summer rainfall. *Weather, London*, **21**, 1966, p. 219.
2. RATCLIFFE, R. A. S.; Forecasting monthly rainfall for England and Wales. *Met. Mag., London*, **97**, 1968, p. 258.
3. LOWNDES, C. A. S.; Forecasting dry spells of three days or more in south-east England from May to October: a revised model. *Met. Mag., London*, **94**, 1965, p. 241.

551.584.41(426)

STUDIES OF TEMPERATURE IN THE FOREST OF THETFORD CHASE — SPRING 1967

By G. W. HURST

Summary. Daily minimum temperature readings were taken at a number of places in the Harling area of Thetford Chase in spring and early summer 1967 at heights varying from 2 in to 72 in over different surfaces and under different conditions, and an analysis was made of the results. Run-of-wind readings were also made and analysed. Maximum and minimum bent-stem 4-in soil thermometers were in use from November 1966 to June 1967 and the observations obtained are discussed.

Introduction. In earlier articles Hurst[1,2] described experiments with minimum thermometers exposed in different locations in Thetford Chase. This paper describes the final set of experiments, in 1967 on a much more restricted geographical scale, in the Harling neighbourhood. Instrumentation was much as before, but anemometers were installed at the different sites, and an interesting additional feature has been the introduction of maximum/minimum bent stem 4-in soil thermometers, with readings from November 1966 onwards.

Minimum air temperatures. Several of these sites were the same as in 1966, and for convenience the same numbers have been retained where possible for the various sites. Temperatures were read in degrees Fahrenheit as in previous years. Site 8, the open bare-soil site at Harling Nursery was again in use with both a shielded minimum thermometer at 4 ft and a mounted array of grass minimum thermometers from 2 in to 72 in. Site 10, the grassed site in the stagnant Harling compartment nearby was similarly instrumented, and so was a new under-cover site, taken as site 1; the percentage of overhead cover, assessed by a light-meter, was about 75 per cent. Site 9, the litter site near site 10, was equipped with 4-ft and 6-in thermometers (the latter without bulb shields) as was site 11, the small area of one square chain of bared soil in the grassed clearing (about 100 yd from site 10) and the nearby site 16 in Harling Ride, a long ride in a north/south direction and 90 ft broad, with trees 40 to 45 ft high on each side; there was a very slight down-slope of about one degree to the north. Run-of-wind anemometers were also installed at nearly all sites, and also for comparison at the completely open country at Kings.

Analysis. It is not proposed to go into the same detail of analysis as in the previous papers, but just to highlight the main results.

Readings at 4 ft. Table I shows the difference between temperatures (corrected for exposure) at the Harling sites and at Mildenhall from 1965 onwards.

TABLE I—DIFFERENCES OF AIR TEMPERATURES AT 4 FEET BETWEEN THE VARIOUS SITES AND MILDENHALL, 1965, 1966 AND 1967 (INCLUDING 1967 SITES ONLY)

Year	Temperature difference, site – Mildenhall for sites: 1	8	9	10	11	16
			degrees Fahrenheit			
1965		−1·3	−2·8	−3·0	−2·3	
1966		−1·8	−3·4	−3·4	−3·0	
1967	−1·0	−1·4	−3·4	−2·9	−3·0	−2·0

Sites: 1. Harling (under cover) 8. Harling Nursery 9. Harling (litter)
10. Harling (grass) 11. Harling (bare earth) 16. Harling Ride

Very little change is shown in Harling Nursery in three years and not much at the other Harling sites, but a curious feature is that for the first time, the temperature at 4 ft above bare soil at site 11 was not quite as warm as that over grass (site 10). The difference is very slight, and could well be due to the increased scrubby vegetation which has grown on the bare plot in the last two or three years. The variations between differences are however small enough to be almost within the limits of experimental error: for example, the 2·9 degF and 3·0 degF of 1967 for sites 10 and 11. The gain in freedom from frost within a ride (site 16) compared with open vegetated land is clear, and air at a height of 4 ft in the under-cover site 1 is distinctly warmer at night than over bare soil at Harling Nursery.

Frequency of years in 10 of frosts after certain dates. The risk of temperatures below 32°F and 28°F after a particular week was again assessed, exactly as before, and results were fairly similar. Table II summarizes the results, with the years 1965 and 1966 also taken into account for sites at which the information was available.

TABLE II—THE EXPECTATION OF AIR FROST AT 4 FEET, EXPRESSED AS THE NUMBER OF YEARS IN 10, AT THE VARIOUS SITES AFTER PARTICULAR DATES

		(a) Temperatures below 32°F						(b) Temperatures below 28°F					
	Week	Site number						Site number					
No.	commencing	1	8	9	10	11	16	1	8	9	10	11	16
		Number of years in 10											
1	1 April	10	10	10	10	10	10	10	10	10	10	10	10
2	8 April	10	10	10	10	10	10	9	10	10	10	10	10
3	15 April	10	10	10	10	10	10	8	10	10	10	10	9
4	22 April	10	10	10	10	10	10	7	9	10	10	10	9
5	29 April	9	10	10	10	10	10	7	9	10	10	10	9
6	6 May	9	10	10	10	10	10	3	7	10	9	9	6
7	13 May	8	9	10	10	10	9	2	6	9	9	8	4
8	20 May	6	8	10	9	9	8	1	3	7	7	6	2
9	27 May	2	5	9	8	8	5	+	2	5	4	3	1
10	3 June	1	2	8	7	6	2	0	1	3	2	2	+
11	10 June	+	1	6	5	4	1	0	+	2	1	1	+
12	17 June	0	0	4	3	2	+	0	+	1	1	1	+
13	24 June	0	0	2	1	1	0	0	0	1	+	+	0

Sites as in Table I, + indicates 0·1 to 0·4

Thus in late May there is still about an even chance of a temperature as low as 28°F at Harling over litter, and much the same over grass, but the risk is considerably lower within a ride or over a large expanse of bare soil; the risk is very low indeed under a forest canopy. There is a slight improvement at Harling Nursery compared with the Harlings in 1967, mainly because of the slightly smaller difference in temperature between Mildenhall and Harling Nursery. Possibly the Nursery has been kept clearer in 1967. Harling Ride is slightly less favourable than the narrower Santon Ride of last year, but the Harling under-cover site is a little warmer than the somewhat less leafy High Lodge and Mundford sites of 1966.

Readings at 6 in. It is not proposed to say very much under this heading. A comparison with Kings as in previous years was not possible, because only weekly readings were being made at that station. Harling Nursery was therefore taken as the standard for 1967, and Table III shows the difference between the other sites and the Nursery for all the available years.

TABLE III—DIFFERENCES OF AIR TEMPERATURES (AVERAGE APRIL TO JUNE) AT 6 INCHES BETWEEN THE VARIOUS SITES AND HARLING NURSERY

	Temperature difference, site – Harling Nursery for sites :				
Year	1	9	10	11	16
			degrees Fahrenheit		
1965		−4·0	−4·4	−2·1	
1966		−4·9	−4·4	−2·1	
1967	−0·4	−5·3	−4·7	−1·8	−2·7

Sites as in Table I.

Interestingly, the grass (10) and the litter (9) sites at Harling are comparatively colder, if anything, and the small bare site less cold in 1967. Again, however, these differences are small and of doubtful significance.

Vertical array. Arrays exactly similar to those of 1966 were assembled. Three arrays instead of two were employed : Harling Nursery as before, Harling grass replacing Mundford as a grassed site in a clearing, and a third was installed at the Harling under-cover site. Figure 1 shows the weekly averages at the various heights for the three locations; the similarity between 1966 Mundford and Harling Nursery (Figure 1, Hurst[2]) and 1967 Harling grass and Harling Nursery is striking. In fact, the average temperature differences between 2 in and 72 in over the 13 weeks for Mundford in 1965 and 1966 and for Harling grass in 1967 were 3·9 degF, 4·5 degF and 4·6 degF; the means of the three coldest nights each week were 5·6 degF, 6·5 degF and 6·4 degF, and the largest inversions in the three seasons were 9·0 degF, 11·3 degF and 9·6 degF. The vertical structure over these rather enclosed grassed sites is thus very similar.

To make a comparison between 1966 and 1967 at Harling Nursery is not easy, as strong doubts exist about the accuracy of the 72-in thermometer in 1967. The instrument was checked on return to Bracknell and appeared in error by about 0·3 degF — just the difference between the average reading at 48 in and at 72 in. In 1966 the average minimum temperatures were virtually uniform from 12 in to 72 in, and apart from the 72 in reading of 40·3°F, the 1967 profile is also practically isothermal at 40·6°F. Because of this uncertainty, comparison of the 72 in and 2 in temperature differences between 1966 and 1967 cannot be made. The array mounted within the canopy brought out several interesting features. An average difference of 1·4 degF existed between 2 in and 72 in, and although the temperatures at 2 in and 6 in were below those above bare soil in the open, the temperature at 24 in (and from there upwards) was higher within the wood than over the open bare ground. The slope of the curve suggested a difference of about 1 degF from the 6-ft level probably to the forest canopy; immediately above this of course the temperature would be much lower, probably of the order of that near the vegetation-covered ground surrounding the wood. Temperature changes within the canopy will of course be far less than those outside, and day maximum temperatures particularly in sunny weather will be far lower than those out in the open.

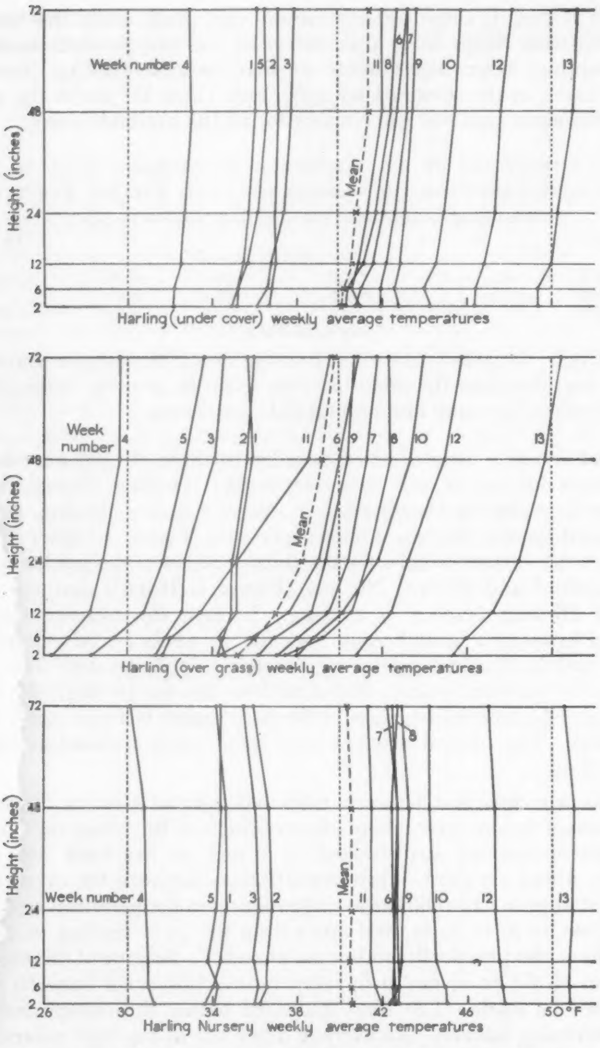

FIGURE 1—VERTICAL TEMPERATURE SOUNDINGS AT HARLING DURING APRIL–JUNE 1967

All three curves on Figure 1 show that week 4 (22–28 April) was outstandingly cold, but week 11 (10–16 June) was also comparatively very cold — and colder over grass than the 13-week mean. This naturally occurred during the period of cold northerly winds, and even near the south coast some overnight ground frost was reported on the mornings of 12 and 13 June. The coldest June night occurred at the end of week 10 on 9 June, with frosts at 4 ft at the other Harling sites, and near frost at Harling Nursery as well.

Cold nights were much more frequent in 1967 than in 1966 or 1965 and the Harling Nursery totals of nights with temperatures below 28°F varied from 5 at 2 in and 6 in to 7 at 12 in and above in 1967 compared with one at all heights in 1966. The total for the under-cover site in 1967 was 4 at 2 in, 2 at 72 in, and 3 at the intermediate heights. Temperatures below 32°F were recorded at all heights at Harling Nursery in the very cold spell in the first part of June, and in subsequent weeks too at the Harling grass site, but no temperatures below 32°F were recorded within the forest canopy after the first few days in May.

Airflow. For the first time in the experiments, run-of-wind anemometers were mounted, 11 in all. Four of these — at Kings, Harling Nursery, Harling litter and Harling grass — had standard agrometeorological (agromet.) exposures of about 6 ft above the ground and, for interest, comparison is made with the agromet. station of Santon Downham, 10 miles to the west-north-west. Five anemometers were exposed at 1 ft, a height more significant to young plants, at the same three sites at Harling and also at the Harling under-cover site and in the nearby ride. Additionally, two were placed at a height of 8 in at Kings, one in the open and the second in a furrow; the Kings anemometers were read weekly, but all the others were read daily at 0900 GMT.

As Figure 2 clearly shows, the windiest site at 6 ft was the open Kings, with a through flow of 14 761 miles during the 3 months; this corresponded to an overall average speed of 6·8 miles per hour, and the greatest weekly flow was 1643 miles from 20 to 26 May (9·8 miles per hour). Harling litter, a little surprisingly, was the second windiest site with a flow of air distinctly greater than that at Harling Nursery (12 134 miles compared with 11 005 miles). The Harling litter site is however rather more open than Harling grass, so the light airflow at the latter is quite acceptable; the total of 9850 miles is a partial estimate, because the anemometer was not exposed until 13 April. The enclosed nature of Santon Downham agromet. station is brought out by the very low value of the 13-week airflow (8950 miles).

Very interesting is the substantially greater air movement at 1 ft in Harling Nursery compared with the other sites. Airflow was about 50 per cent more than in the Harling compartment, where the air movement over the litter site was distinctly greater than over grass, as Figure 2*(b)* shows. Perhaps predictably, with its channelling of airflow (and therefore lessening of any cross-wind component) the wind in the ride was lighter, and very predictably the airflow within the forest (site 1) was much lower, amounting to only about 10 per cent of that at Harling Nursery. It is not intended to dwell on the Kings instruments, at a different height from the other anemometers, and read only weekly. The results have however been plotted on Figure 2*(b)* for comparison; this showed that the flow in the open at 8 in at Kings (4317 miles) is very similar to that over grass at Harling, especially in April and May. The 8-in anemometer in a furrow is obviously very protected, with a 13-week flow even less (704 miles) than the flow within the forest canopy at a height of 1 ft, where the total flow was 846 miles (a mean wind speed of 0·4 miles per hour).

In general, it can probably be concluded that over an open surface (exemplified by Harling Nursery) the wind at 1 ft is about two-thirds that at 6 ft, but that in a more stagnant terrain covered by grass or other low

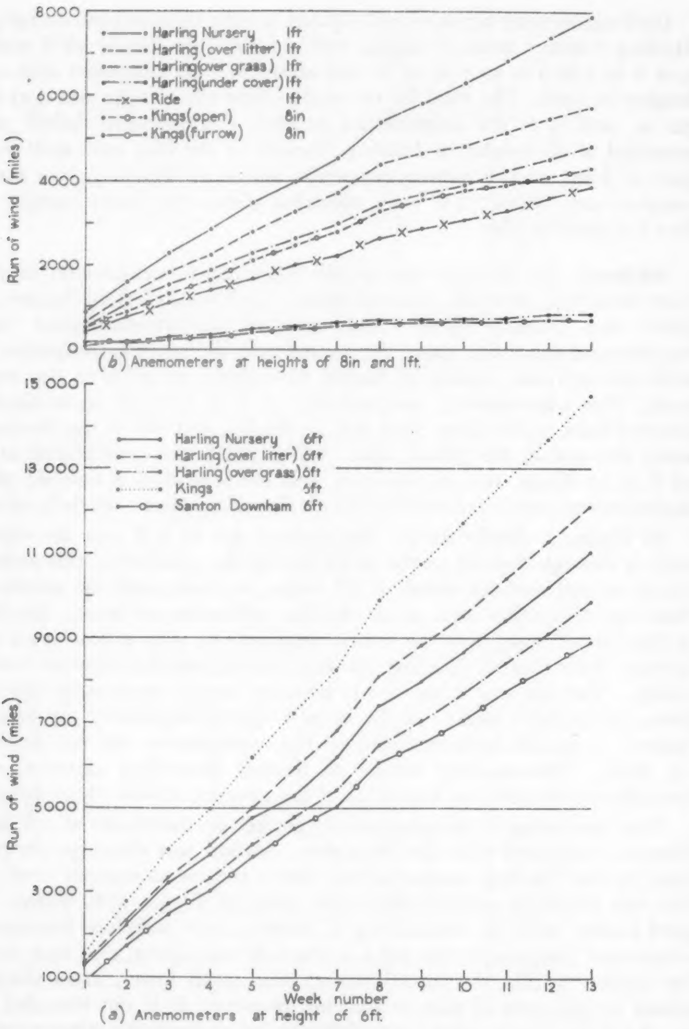

FIGURE 2—WEEKLY TOTALS OF RUN OF WIND AT VARIOUS SITES AT THETFORD APRIL–JUNE 1967

vegetation, the factor is about half. Over similar vegetation at Kings, the airflow at 3 in was about one-third that at 6 ft, but airflow in furrows was relatively very light indeed. Finally, the records did not suggest any unserviceability of the anemometers, as the pattern of the divergence between the various sites was very similar from one week to the next.

Soil thermometers. Five maximum/minimum bent-stem 4-in soil thermometers were installed from November 1966 to June 1967 at the five

sites 1, 8, 9, 10 and 11. At sites 8 and 11 the instruments were put into the bare soil. At the other three sites (the litter site 9, the grass site 10 and the under-cover site 1) a tiny bare patch was cleared for the instrument. In January 1967, a sixth instrument was installed at the grassed site 10 with the absolute minimum of disturbance of the vegetation, and this is known as site 10*a*.

Well demonstrated in Table IV is the greater diurnal variation at Harling Nursery, and at the bare-soil site at Harling, sites 8 and 11, at all times of the year; only in cold January was there any other station within 1 degF of the diurnal variation of either of these two sites. Differences in pattern between the two bare-soil sites is slight, so the size of the bare-soil patch is not very significant in this respect, once a reasonable size has been attained. The diurnal variation is large in June, averaging about 15 degF (and a maximum of 25·8 degF). The litter site 9 with a small cleared square for the thermometer showed the next largest variation — a little more than site 10, but rather similar in most respects. This difference between sites 9 and 10 showed up consistently, with slightly higher maximum temperatures at site 9 throughout (averaging 1 degF difference a day), but the pattern of minima showed a change over the period, with site 10 less cold at night up to May.

The diurnal variation at the under-cover site 1 was the lowest of all the variations from sites with a continuous record throughout, being just about half that of sites 8 and 11; its mean daily maximum temperature in June was 10 degF below that at these sites. It gained over the other places in January, with an average night temperature over 37°F, 0·6 degF warmer than any other location; and indeed from November to March site 1 was the warmest site, with high minimum and not low maximum temperatures. By June it was easily the coldest, by day and by night. Finally, the fully grassed site 10*a* was in operation for only part of the time, but showed throughout its five months a considerably smaller daily range than site 11. The heat was very well retained at night, and only in June was the average night minimum at 4-in depth higher under the bare soil than under the grass carpet of site 11 — otherwise the grass cover provided the warmest soil. Day maxima of course were conspicuously low.

The data were also partly analysed for variability, standard deviations being calculated for the months of November, January (the month with the lowest diurnal variation) and June. In November, they ranged from 2·3 degF and 2·4 degF for sites 8 and 11 to 1·3 degF for sites 1 and 10; in January the variability is similar, but in June the standard deviation is as high as 5·1 degF at site 8, 4·7 degF at site 11 (and 4·5 degF at site 9), down to 1·8 degF at site 1 and 1·9 degF at site 10*a*. The winter figures were made slightly more difficult to analyse because a few of the figures were negative — a higher minimum value on one day than the maximum read the next ! The difficulties of reading such instruments in conditions of cold weather with snow or frost on the ground are fully recognized.

An indication of the range of diurnal variation is of interest. Greatest of course in June, highest values reached were 25·4 degF at site 8 on the 13th and 22·3 degF on site 11; lowest figures for these sites in this month were 5·3 degF and 4·7 degF respectively. These compared with the under-cover site 1 values of 9·9 degF and 3·2 degF, and the grass-covered sites values of 10·3 degF and 2·7 degF. In winter there were periods with frost (such as

TABLE IV—MONTHLY MEAN MAXIMUM AND MINIMUM SOIL TEMPERATURES AT FOUR INCHES AND MEAN DIURNAL VARIATION NOVEMBER 1966 – JUNE 1967

Site No.	1			8			9			10			11			10a		
Month	X	N	DV	X	N	DV	X	N	DV	X	N	DV	X	N	DV	X	N	DV
										degrees Fahrenheit								
Nov. 1966	43·8	41·9	1·9	42·8	37·9	4·9	44·2	40·6	3·6	43·9	41·8	2·1	42·3	37·8	4·5			
Dec. 1966	41·3	38·2	3·1	40·2	34·7	5·5	41·0	36·7	4·3	40·4	37·9	2·5	40·0	34·7	5·3			
Jan. 1967	39·1	37·3	1·8	37·8	35·0	2·8	38·7	36·0	2·7	38·3	36·7	1·6	37·3	34·5	2·8			
Feb. 1967	41·5	38·3	3·2	41·4	35·8	5·6	41·6	37·0	4·6	40·7	37·9	2·8	41·1	35·6	5·5	40·9	39·0	1·9
Mar. 1967	44·7	40·8	3·9	47·0	38·6	8·4	46·3	40·0	6·3	44·7	40·5	4·2	47·9	39·2	8·7	43·8	41·4	2·4
Apr. 1967	46·6	41·3	5·3	50·5	40·0	10·5	49·6	41·4	8·2	48·2	41·6	6·6	51·4	40·5	10·9	46·5	42·5	4·0
May 1967	53·2	46·7	6·5	58·7	46·6	12·1	56·6	47·4	9·2	55·4	47·6	7·8	60·6	47·6	13·0	53·4	48·5	4·9
June 1967	58·3	51·6	6·7	69·2	54·4	14·8	63·8	53·4	10·4	62·0	53·2	8·8	70·1	55·9	14·2	60·0	53·7	6·3

X = 24-hour maximum temperature read at 0900 GMT N = 24-hour minimum temperature DV = diurnal variation of temperature

Sites : 1. Harling under cover 8. Harling Nursery 9. Harling litter 10. Harling grass 11. Harling (bare earth) 10a. Harling grass (undisturbed)

4–13 January) when diurnal variation was virtually nil at sites 8 and 11 with temperatures just below freezing. The winter was so mild however that cold weather did not persist long enough for frost to penetrate to 4 in elsewhere.

Rather similar experiments were undertaken by Rider[3] in 1954–55 with thermometers at various depths in the clay at Cambridge; records at 10 centimetres (4 in) showed much smaller values of diurnal change than experienced in the sandy soil of Thetford, but the ratio of diurnal variation under bare earth to that under a vegetated surface was of about the same order. It is also interesting to note that Johnson and Davies[4] in experiments on Salisbury Plain with different types of soil, found, with sand, values for diurnal variation of temperature reasonably consistent with those found at Thetford.

Finally, it is of interest to examine average temperatures at a depth of 4 in at Thetford.

Figure 3 is a composite diagram showing *(a)* monthly data of average air temperatures and sunshine, and rainfall totals for Santon Downham, together with the average 4-in soil temperatures for site 8, and *(b)* average monthly values of the soil temperatures at the other sites minus site 8. This Harling Nursery site (8) was selected as the datum because it was representative of

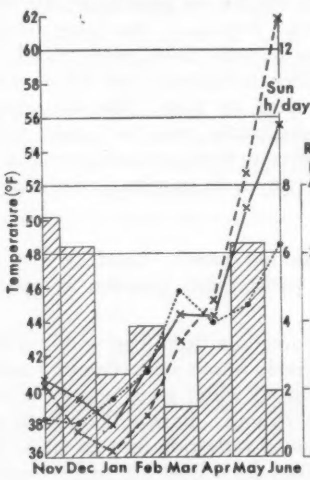

FIGURE 3 *(a)* — THETFORD AREA CLIMATOLOGICAL DATA AND SOIL TEMPERATURE MEANS FOR NOVEMBER 1966–JUNE 1967

x———x Mean air temp. Santon Downham
• . . . . • Mean sunshine Santon Downham
x- - - -x Soil temp. site 8 (Harling Nursery)
Shaded area = total rainfall Santon Downham

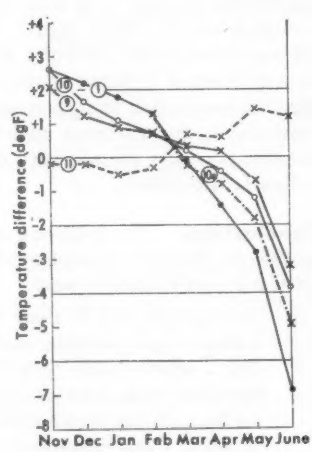

FIGURE 3 *(b)* — SOIL TEMPERATURES AT VARIOUS SITES MINUS SITE 8 (HARLING NURSERY)

•———• Site 1 minus site 8
x———x Site 9 minus site 8
o———o Site 10 minus site 8
x-·-·-x Site 10*a* minus site 8
x- - - -x Site 11 minus site 8

a fairly exposed expanse of bare soil, and because it has frequently been used as a standard when comparing air temperatures in past experiments.

First considering the absolute readings, a mild winter was followed by an exceptionally mild and sunny early spring, a rather cold dull April, and frosts early in May. This is reflected by the average soil temperatures being rather lower than the air temperatures in winter, with a marked reversal for site 8 in early summer. Santon Downham is probably distinctly colder than Harling Nursery, so that the contrast at the former between soil and air temperatures will be greater in winter and less in summer.

Changes in the pattern of differences in soil temperatures between the various sites over the eight months are striking. Site 11, the moderate-sized bare-soil patch in Harling, changes little in relation to site 8, and broadly, temperatures in Harling Nursery are rather above those of the other Harling sites in winter, and rather below in spring and summer. This difference is seen in both day maximum and night minimum temperatures, and may reflect the greater stagnancy of air in Harling, with colder (air) temperatures in winter and greater warming in the summer.

The other four locations behave very similarly to each other — all several degrees warmer under a protective cover, be it grass, litter or forest canopy in winter, and very much colder in summer than under bare earth (e.g. site 8). The differences from November to March, in particular, are small, temperatures at sites 1, 9 and 10 and (from February) 10*a* lying within a one degree range. From April, differences become more pronounced, with an almost clear pattern in which site 1 is colder throughout, and site 9 warmer, with a difference between them of over 3 degF by June. The site with the coldest summer earth temperatures, very predictably, was that under a forest canopy site 1, and the next coldest was the completely grassed over site 10*a*. The other two sites are not very dissimilar (tiny bare patches), with the grass site slightly the colder.

Conclusions. The following conclusions are mostly based on the 1967 experiments, but for completeness some background mention is made of what was found in earlier work.

(i) At a height of 4 ft, there was more freedom from frost within a forest canopy than outside (and appreciably more with denser canopy), but a narrow ride (less than say 20 yd wide) gives almost as much freedom from frost as 70 per cent canopy. Bare soil over an open surface affords better protection than a wide ride (say 30 yd or more across). Least favourable for freedom from frost are rather enclosed vegetation-covered sites.

(ii) The findings above are reflected in years of freedom from frost. Thus at the start of June the risk of temperatures of below 28°F ranged from 5 years in 10 in places like Harling to 2 years in 10 at Harling Nursery or in a broad ride, and 1 year in 10 in a narrow ride or under light canopy. The risk is low under denser canopy.

(iii) At a height of 6 in above the ground, differences in temperature in various exposures are considerably greater than at 4 ft. On the whole, a large expanse of bare soil affords maximum protection against cold temperatures, but dense canopy can give greater freedom

from low temperatures in a sudden short cold spell. Narrow rides are probably the next best frost preventer, followed in order by a small bare-earth area and a wide ride.

(iv) The vertical arrays show that freedom from low temperatures was maintained at all heights between 2 in and 72 in over bare soil, with very big gains over natural vegetation, especially near the ground. The temperature in the lowest few inches under forest cover was lower than over bare soil, but above 2 ft the temperature within the canopy was higher.

(v) Airflow at 6 ft is controlled mostly by the openness of the terrain, but at 1 ft or below the type of earth cover is important. Airflow near the ground was greatest over bare soil, and least within the canopy or near the level of a furrow top.

(vi) Temperatures in late spring and early summer in sandy soil show a change of pattern. In early/mid spring, minimum temperatures are lower under bare soil than elsewhere, but in late spring and in early summer, night temperatures are less cold under bare soil than under vegetation or within a forest canopy. Average maximum day temperatures are always higher in spring and summer under bare soil than under some form of cover, and in June can average over 10 degF higher than soil temperatures under a forest canopy.

(vii) Gradual changes in cover (such as more grass at Kings since 1965) bring about a changed frost risk above ground.

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REFERENCES

1. HURST, G. W.; Temperatures in the forest of Thetford Chase. *Met. Mag., London*, **95**, 1966, p. 273.
2. HURST, G. W.; Further studies of minimum temperature in the forest of Thetford Chase. *Met. Mag., London*, **96**, 1967, p. 135.
3. RIDER, N. E.; Soil temperature under various surfaces near Cambridge — some preliminary results. London, Meteorological Office, 1955. (Unpublished, available in the Meteorological Office Library, Bracknell.)
4. JOHNSON, N. K. and DAVIES, E. L.; Some measurements of temperatures near the surface in various kinds of soils. *Q. Jnl R. met. Soc., London*, **53**, 1927, p. 45.

551.509.322.7:311.214:629.13:681.3

THE COMPARISON OF SUBJECTIVE AND OBJECTIVE UPPER AIR FORECASTS FOR AVIATION (PART II)

By I. H. CHUTER, M.Sc.

Summary. Part I of this paper (published in January) compared subjective forecasts of the 300 mb height field with objective forecasts produced by means of a linear regression equation using the 1000, 500 and 200 mb forecast height fields. An objective method was used to compare the actual equivalent headwinds over a given route with those forecast. (Assessments were made on the 0000 GMT analyses charts and on the forecast charts valid for the same time — normally a 24-hour forecast.) The period covered was from August 1966–July 1967 giving about 360 forecasts, and these have been analysed in 3 sets of 120.

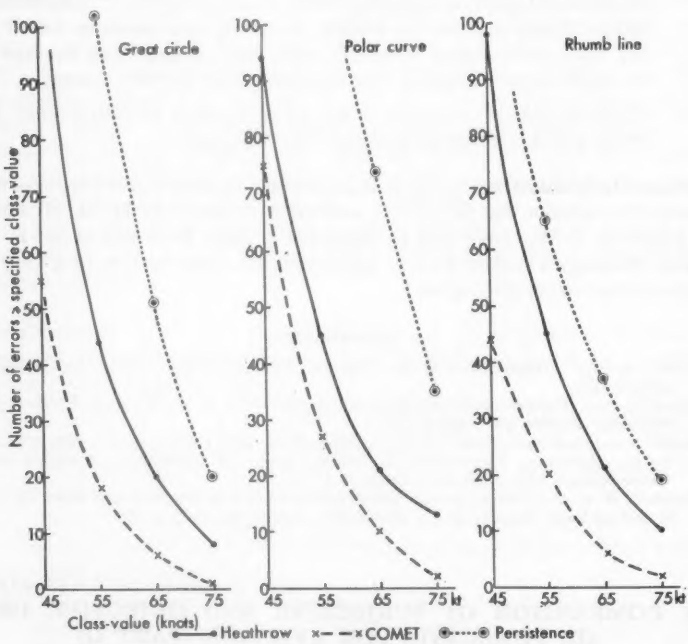
Headwinds were also converted into total flight times and assessments were made of timing errors in relation to the needs of airline operators. Root-mean-square errors in the objective forecasts of headwinds were lower than in subjective forecasts. An analysis of the total errors on each route showed that large errors were fewer in the objective forecasts than in the subjective.

Part II gives an analysis of errors in headwinds for individual 300 nautical mile zones on the air routes showing that the objective forecasting method was better than the subjective, and that forecast success does not depend on the geographical location of the zone. An analysis of the errors in estimated flight times shows that subjective methods increased the mean error. Some of the possible sources of error in the data are discussed.

Results and discussion. (Continued from Part I[1].)

Individual zone errors. The treatment of total route errors may be considered as a rather insensitive test and an analysis was made of individual zone errors, the zones being approximately 300 nautical miles in length.

The errors were sorted into 10-kt classes and, as before, the number of cases of errors greater than or equal to a specified value were assessed. The results for the three periods, forecasts and routes are shown in Figures 1 *(a)–(c)*. Each curve is a portion of an assessment of about 1200 values. The tables



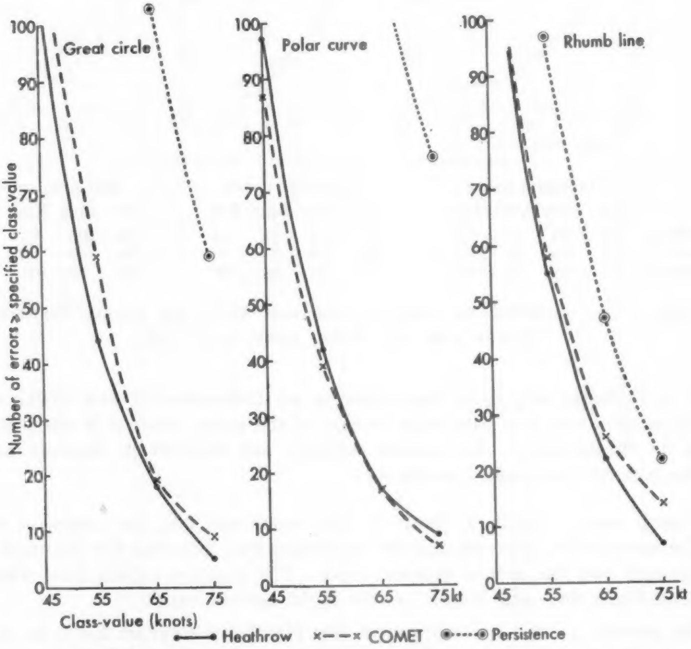
	Maximum errors				Maximum errors				Maximum errors			
	Aug.	Sept.	Oct.	Nov.	Aug.	Sept.	Oct.	Nov.	Aug.	Sept.	Oct.	Nov.
Heathrow	65	85	85	75	75	80	155	80	70	65	100	70
COMET	62	61	66	72	63	57	82	67	61	72	74	64
Persistence	85	85	125	85	80	115	135	120	90	80	85	100

FIGURE 1 *(a)*—NUMBER OF ERRORS GREATER THAN OR EQUAL TO SPECIFIED VALUE FOR THE ZONE, AUGUST–NOVEMBER 1966

beneath each set of curves indicate the maximum zone errors for each forecast for each month and the highest value may be considered as the point where the curves intersect the class speed axis.

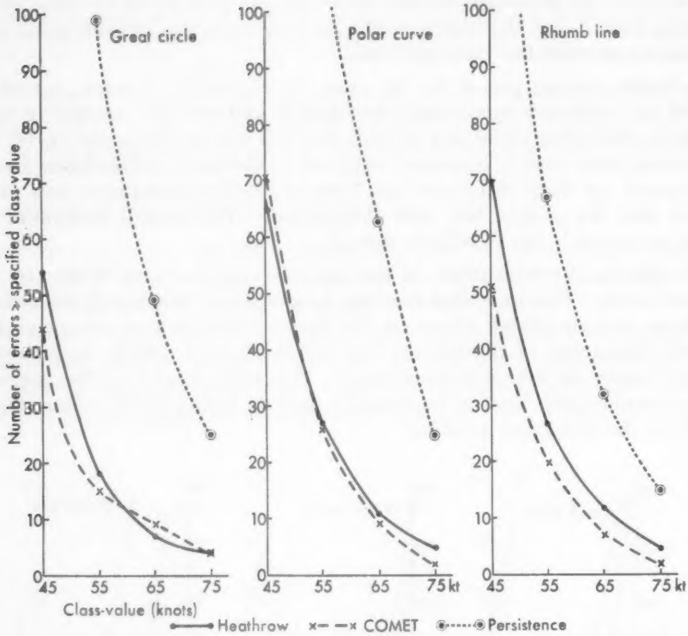
As before, during period (1) the COMET performance is better, but during period (2) subjective amendment has slightly reduced the number of higher errors on the great circle and rhumb line but not on the polar curve. The maximum zone error is however contained in the London/Heathrow forecast. For period (3) little difference has been made by amendment and for the rhumb line the change has been detrimental. The overall maximum zone errors are again in the Heathrow forecast.

An analysis was also made of the highest errors for each of the 10 zones of each track. This indicated that the geographical location of the zone did not have any significant effect on the forecast performance except with the western five zones of the rhumb line COMET forecast, which, in period (2), showed errors at the persistence level. This adds weight to the suggestion that a winter effect such as sea-heating may be failing in the COMET forecast model in this particular location.



	Maximum errors				Maximum errors				Maximum errors			
	Dec.	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.	Dec.	Jan.	Feb.	Mar.
Heathrow	125	70	70	75	85	85	80	100	85	70	70	85
COMET	96	71	91	81	78	68	75	91	102	80	73	97
Persistence	190	140	115	100	200	155	115	95	100	80	115	75

FIGURE 1 *(b)*—NUMBER OF ERRORS GREATER THAN OR EQUAL TO SPECIFIED VALUE FOR THE ZONE, DECEMBER 1966–MARCH 1967



	Maximum errors				Maximum errors				Maximum errors			
	Apr.	May	June	July	Apr.	May	June	July	Apr.	May	June	July
Heathrow	75	105	75	60	80	75	85	55	80	105	65	50
COMET	72	85	61	48	68	78	72	56	83	66	69	51
Persistence	85	145	85	85	90	90	75	80	125	80	100	70

FIGURE 1 *(c)*—NUMBER OF ERRORS GREATER THAN OR EQUAL TO SPECIFIED VALUE FOR THE ZONE, APRIL–JULY 1967

It is perhaps surprising that there is no indication of any difference in performance over any particular section of the route, since it is often thought that developments in the eastern Atlantic are difficult to forecast because of the lack of observations to the west.

Timing errors. Table I shows a frequency analysis, in 5-minute classes of the time errors, representing the economic loss, between the planned least-time-route and the actual shortest route. The positive values arise when the forecast flight time was larger, i.e. the flight arrived early.

For period (1) it is quite apparent the Heathrow forecast has a far greater spread of errors than that of COMET, and this is reflected in the calculated standard deviation. For periods (2) and (3) the standard deviations are almost identical in the two methods but the mean error has been increased by between four and five minutes by subjective intervention. This suggests that when track selection is involved a 'safety factor' is incorporated by the human forecaster and this may be linked to the increasing of jet core-speeds mentioned earlier.

TABLE I—ANALYSIS OF ERRORS IN FOUR-MONTH PERIODS

Period 1 August–November 1966

Error range (minutes)

	Negative values											Positive values												Standard
	55–51	50–46	45–41	40–36	35–31	30–26	25–21	20–16	15–11	10–6	5–1	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	Mean	deviation
(a)					1	2	3	6	9	20	18	18	15	18	7	3	1	1					+0·1	12·0
(b)							2	3	16	12	28	28	19	7	5								−1·1	8·7
(c)			1	1	0	2	0	15	10	15	13	20	13	11	11	7	1	1					−0·3	13·8

Period 2 December 1966–March 1967

Error range (minutes)

	Negative values											Positive values												Standard
	55–51	50–46	45–41	40–36	35–31	30–26	25–21	20–16	15–11	10–6	5–1	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	Mean	deviation
(a)					1	1	3	8	3	11	18	13	17	19	6	7	3	7	2	1	1		+5·0	15·0
(b)					1	2	6	6	11	14	11	21	17	8	9	7	5	2	0	0	1		+1·0	14·9
(c)	1	2	1	5	4	4	7	6	7	8	11	10	9	13	16	4	3	5	2	0	2	1	−0·1	21·8

Period 3 April–July 1967

Error range (minutes)

	Negative values											Positive values												Standard
	55–51	50–46	45–41	40–36	35–31	30–26	25–21	20–16	15–11	10–6	5–1	0–4	5–9	10–14	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	Mean	deviation
(a)							1	4	9	14	21	30	13	17	8	3	1	1					+2·0	9·8
(b)							4	9	16	17	22	20	19	10	3	1							−2·7	10·3
(c)				1	1	2	5	9	13	14	22	12	10	12	8	5	5	2	0	1			−0·2	15·0

(a) = Heathrow (b) = COMET and (c) = Persistence

The relative merits of early or late arrivals are open to discussion and may depend on the preferences of the operators. Punctuality could be ensured by varying speed and therefore fuel consumption in flight but in practice any gains from such manoeuvres are likely to be counteracted by air traffic control procedures.

Sources of possible errors. In many cases the forecast performance is judged on small differences in r.m.s. errors and it is of interest to estimate some of the errors involved in the measurements.

Assessment of true winds. The best assessment available of the true winds along a track at a given time is that from the Heathrow analysis charts. It should be noted here that although actual aircraft reports are of value, great care is required in their use. The reports are rarely at the precise height, time and position to be used on a particular part of the chart, and since they are spot winds they are subject to gustiness of varying periods. This latter effect may make them unrepresentative of the flow on the synoptic scale. In contrast, the wind measured by balloon and radar is the mean through a layer of a few thousand feet.

The assessment of a wind speed by eye from a chart is also subject to error, and it is well known that if several forecasters take measurements on the same chart different values may be obtained. A previous assessment[2] of this effect indicates that a standard deviation of about two knots may be involved for a route of 10 zones of 300 nautical miles.

It is necessary to measure the geostrophic wind over some distance which will depend, in the subjective case, on the lateral spacing of the contours and the angle made with the track. Distances probably lie on average between about 100 and 200 nautical miles. The wind is then applied to a nomogram to obtain the headwind, and directional errors can be introduced at this stage. The quoting of the result to the nearest 5 kt is probably sufficiently precise. Even if each zone of a track had 5-kt errors it is unlikely that they would all be in the same sense, so measurement errors for the total track will be considerably less than 5 kt.

COMET assesses the gradient through a grid square, about 160 nautical miles, and applies this wind to the length of track in that square. The calculation of headwind is then precise.

The forecast comparisons are, however, with respect to the standard analysis values, so even if these are in error the relative performance will be unaffected.

Effect of aircraft speed. The basis of all the calculations is an aircraft speed of 400 kt and thus relative performance is unaffected by changing this speed.

However, timing errors do depend on the aircraft speed, as does the absolute value of the headwind.

The contribution to total headwind of the beam component of wind velocity is given by $(V^2 \sin^2\theta)/2A$ where V is the wind velocity, θ the angle to the track and A the aircraft speed. The maximum effect is then $V^2/2A$.

Considering an aircraft speed of say 500 kt the difference in beam component is

$$\frac{V^2}{2}\left(\frac{1}{400}-\frac{1}{500}\right)=\frac{V^2}{2}\,\frac{1}{2000}=\frac{V^2}{4000}\quad .$$

For a wind speed of 100 kt the difference would be about 2 kt. Since the track of the aircraft would be at right-angles to a jet stream to achieve this difference, it would soon pass across the belt of strong winds and the effect on the total route headwind would be small.

Thus changes of aircraft speed of this order can be neglected for headwind calculations.

The effect of aircraft speed on the time for a route of 3000 nautical miles is more complex but in near still-air conditions an error of 15 min at 400 kt is equivalent to about 10 min at 500 kt.

Conclusions and future developments. It is evident that the decision to introduce numerically produced forecasts for aviation purposes was well founded, because there is an improvement both in meteorological and economic terms. It is now possible for airline operators to produce flight plans by computer direct from forecast height fields.

The present method of producing the COMET 300 mb height field is extremely primitive and the scope for improvement is considerable.

The conclusion from the period December 1966 – March 1967 is that subjective intervention has resulted in no significant improvement to the COMET forcasts as determined by the equivalent headwinds over the whole routes. Consideration of individual zone errors indicates a marginal improvement in the number of large errors during the winter period on the great circle and rhumb line, but this trend is not continued in the subsequent period.

It is clear that the facility for human intervention has to be used with care to be justified.

REFERENCE

1. CHUTER, I. H.; The comparison of subjective and objective upper air forecasts for aviation (Part I). *Met. Mag., London*, **98**, 1969, p. 19.
2. HOWKINS, G. A. and CHUTER, I. H.; Comparison of equivalent headwinds from 300 mb objective numerical forecasts and subjective forecasts. (Unpublished, copy available in the Meteorological Office Library, Bracknell.)

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SOME OBSERVATIONS OF NIGHT MINIMUM ROAD TEMPERATURES

By J. S. HAY

Summary. Air and road surface temperatures were measured during two successive winters at each of two sites. Differences in the night-minimum values of these temperatures were generally small and no systematic variation with a number of meteorological and other parameters was evident. Two types of situation were recognizable however, in one of which the minimum air temperature was consistently higher than the minimum road temperature and in the other, consistently less, the difference being up to 3 degC or so at times.

When he is considering whether or not to issue a warning of icy roads for the ensuing night, a forecaster obviously must arrive at some estimate of the minimum temperature to be expected on roads in the forecast area.

Various techniques are available to him for forecasting minimum air temperature, but just how this is related to minimum road temperature is not at all clear as little relevant information appears to have been published. The relation between minimum air and grass temperatures on the other hand has been discussed in a number of papers, [1,2,3] but this cannot be assumed *a priori* applicable to roads in view of the very different natures, and presumably very different thermal properties, of grass and road surfaces.

This article is concerned with measurements of road and air temperatures which were made in the course of tests on ice-warning devices, on the carriageway of the M 1 motorway near Newport Pagnell during the winters of 1963/64 and 1964/65, and on a slip road off the M 4 motorway near Bray Wick during the succeeding two winters. The temperature sensors were thermocouples which were connected to a recording potentiometer containing an automatic reference junction. At both sites, one thermocouple junction and the first metre or so of the leads were embedded in the asphalt surface of the road so that the upper surface of the junction was exposed to the air. Another thermocouple was set up on the grass verge with its junction in a Stevenson screen at the standard height of 1·25 m. The resistance between metal plates embedded in the road surface was also recorded, thereby giving an indication of whether the surface was wet or dry. No other observations were made at Newport Pagnell but additional recorded measurements at Bray Wick included wind speed, net radiation and wet-bulb depression.

At the Newport Pagnell site, the carriageway of the M 1 runs in a south-east to north-west direction over level ground. The exposure of the Stevenson screen was poor to the south-west, with a solid fence nearby and some buildings beyond, but was otherwise satisfactory. At the time of the observations, the carriageway comprised a 10-cm rolled asphalt surface on a 35-cm lean-mix concrete base with a hoggin sub-base. At Bray Wick, the instruments were located at the start of a north–south section of the slip road, just after it curves sharply off the eastbound carriageway of the M 4. The adjoining ground to the east was level with the road surface but to the west, lay about 2 m below the road. The site was well exposed, the only obstructions being some buildings 30 m or so to the west. The road consisted of a 10-cm rolled asphalt surface and a 40-cm cement-stabilized base with a gravel sub-base.

For the purposes of the present analysis, minimum air (M_A) and minimum road (M_R) temperatures in degrees Celsius between the hours of 2100 and 0900 GMT next day were noted from the potentiometer charts, and the differences $D = M_A - M_R$ were determined. D was found to be substantially constant for much of the winter, as will be seen from Figure 1 where, for the sake of clarity, 10-day mean values are plotted. For the winter periods, the overall mean and extreme values of D were as follows :

Site	Newport Pagnell	Bray Wick
Period	Mid-November to end of January	Mid-November to end of February
No. of observations	121	171
Mean D degC	−0·1	+0·7
Max. D degC	+2·5	+3·2
Min. D degC	−6·2	−1·9

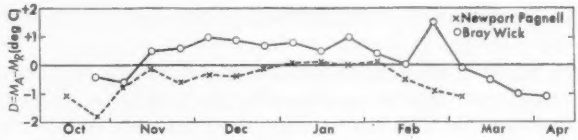

FIGURE 1—VARIATION OF 10-DAY MEAN VALUES OF D

However real the difference of 0·8 degC in these mean values of D may be, meteorologically it is probably of little consequence, being less than the usual error in forecast values of minimum air temperature. Combining the two sets of data then, the mean value of D may be taken as 0·3 degC or, rounding off to the nearest whole number, 0 degC.

Another feature to be noted from Figure 1 is that at both sites, before and after the winter periods used for determining the longer period means, D is essentially negative, i.e. minimum road temperature higher than minimum air temperature. This is no doubt due, in part at least, to the greater absorption of solar radiation by the asphalt road surface than by the adjoining grass surfaces. These remarks apply equally well of course to the winter months but, with lower solar elevations and shorter duration of daylight, the difference in absorption then will be less marked. Another factor possibly contributing to these negative values of D is the fact that the thermocouple measuring air temperature was above the grass verge. However, even if it was over the road surface, this is of such limited extent that, only in exceptional circumstances, would the screen temperature at 1·25 m be governed exclusivley by heat transfer processes above the road.

On physical grounds, the value of D may be expected to be dependent, among other things, on wind speed and cloud cover prior to the attainment of minimum temperature, e.g. large positive values with clear skies and light winds. The data for Bray Wick were thus considered in greater detail as some supporting observations were available for this site. These did not actually include cloud cover but it seemed reasonable to assume net radiation to be inversely proportional to amount of cloud. Mean values of radiation and of wind speed were determined each night for the 3-hour period preceding the time of minimum temperature, or the earlier minimum when M_A and M_R were reached at different times. When the values of D were grouped according to wind speed and radiation, D was seen to be generally positive in sign for moderate and stronger winds, but otherwise did not vary systematically with these two variables. From further grouping or plotting of the data, there appeared also to be no dependence of D on :

(i) the road surface being wet or dry,
(ii) traffic density,
(iii) the value of air or road minimum temperature,
(iv) the times at which the minima occurred,
(v) the time interval, sometimes several hours, between the two minima,
(vi) wet-bulb depression.

Finding (ii) was based on the observations at Newport Pagnell, for which site hourly traffic counts were available.

The meteorological situations obtaining on occasions of extreme positive and negative values of D were next considered to see whether or not any

characteristic features were recognizable. Two facts to emerge were as follows :

(i) If fog forms in the area, negative values of *D* of 3 degC or more may be obtained. This seems somewhat surprising since positive values of *D* might be expected in such conditions, at least before the fog formed. In some instances, the incidence of fog, judging by the high humidity and a sudden drop in outgoing radiation, was accompanied by a drop of a few degrees in air temperature whereas the road temperature remained more or less constant.

(ii) If insolation, after a night of clear skies and light winds, is curtailed soon after sunrise by the spread of cloud ahead of a warm front, with the warm, cloudy air mass subsequently reaching the area, positive values of up to 3 degC for *D* will be obtained on the *following* night.

These two types of situation are illustrated in the temperature sequences shown in Figure 2. During the night of 28/29 December 1965, light winds and clear skies were fairly general over eastern England as a ridge moved from west to east across the British Isles. Some fog patches were reported from London/Heathrow Airport, about 20 km to the east of Bray Wick, and other places; the Bray Wick observations were consistent with the presence of fog. The value of *D* for the night was − 1·5 degC. Around 0800 GMT on the 29th, cloud increased rapidly at Heathrow and, a few hours later, rain reached the area in advance of a warm front then moving into western districts of England. The warm front moved steadily eastwards to cross the area during the evening, being followed soon afterwards by the cold front. Thereafter the skies were largely clear for the remainder of the night though there were one or two light showers. The value of *D* for the night of 29/30 December was +2·7 degC. Apart from two brief spells around noon on 1 and 2 January 1966, the air temperature remained above the road surface temperature until the afternoon of the 3rd.

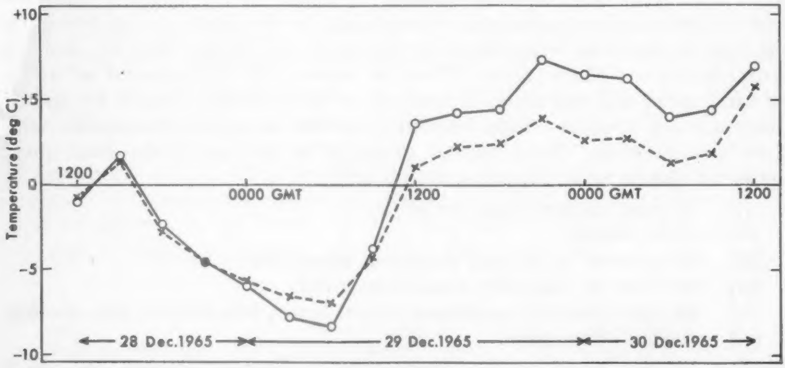

FIGURE 2—AIR AND ROAD SURFACE TEMPERATURES AT BRAY WICK FROM 1200 GMT ON 28 DECEMBER 1965 TO 1200 GMT ON 30 DECEMBER 1965
o = air temperature x = road temperature.

If the above findings are applied now to the problem of forecasting, it would appear that forecast values of M_R should be taken to be the same as forecast values of M_A for the period mid-November to mid-February. This however, should perhaps be regarded at the present stage as a guide rather than a rule in view of the limited amount of data, two incomplete winters at each site. It may be, too, that a different result would be obtained at another site with different topographical features and physical characteristics such as type of road construction, colour of surface, etc.

No mention has been made so far of the accuracy of the temperature measurements. There seems little reason to doubt the road surface temperatures as the thermocouple junction at each site was in good thermal contact with the road, and there could have been little or no thermal conduction along the leads to the junction. To check the air temperatures, the observed minima were compared with the minima measured at the nearest meteorological offices. In the case of Newport Pagnell, the mean difference from Cardington minima was −0·4 degC (96 per cent of the differences within 2 degC), while for Bray Wick the mean difference from London/Heathrow Airport minima was 0·2 degC (98 per cent of the differences within 2 degC). As the distances separating the sites under comparison were about 25 and 20 km respectively, the agreement is remarkably good. The temperature measurements used in the above analysis can thus be accepted with confidence.

The measurements were made in the course of work carried out by the Climate and Environment Section (Leader Mr L. H. Watkins) of the Ministry of Transport's Road Research Laboratory, and this article is contributed by permission of the Director of Road Research.

The assistance of Mr A. O. Grigg and Miss W. McHugh in extracting and analysing the data is gratefully acknowledged.

REFERENCES

1. CRADDOCK, J. M. and PRITCHARD, D.; Forecasting the formation of radiation fog — a preliminary approach. (Unpublished, copy available in the Meteorological Office Library, Bracknell.)
2. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Q. Jnl R. met. Soc., London*, **78**, 1952, p. 603.
3. MULDNER, W.; Die Vorhersage des nächtlichen Temperaturminimums mit hilfe der Ausgleichsrechnung. Meteorologische Rundschau **14**, No. 6, 1961, p. 170. (The prediction of nocturnal temperature minima by means of a balancing calculation. R.A.E. Library Translation 1226, unpublished, copy available in the Meteorological Office Library, Bracknell.)

AWARDS

L. G. Groves Memorial Prizes and Awards

In 1946 Major and Mrs Keith Groves instituted three annual prizes in memory of their son, Sergeant (Meteorological Air Observer) Louis Grimble Groves, RAFVR, No. 517 Squadron, Coastal Command, who lost his life while flying on a meteorological sortie on 10 September 1945. In addition a general purpose award, named the Second Memorial Award, was set up in 1960.

On 22 November 1968 the four awards for the year were presented at the Ministry of Defence, Whitehall, by Major K. J. Groves. The presentation was presided over by Air Marshal Sir Peter Wykeham.

The 1968 Aircraft Safety Prize was awarded to Flight Lieutenant J. F. Narramore, B.E.M., an Engineering Officer of Royal Air Force Lyneham, with the following citation :

> 'In recognition of his diligence, skill and impressive contribution to flight safety. Flight Lieutenant Narramore, an Engineering Officer, was responsible for the investigation of engineering defects involving the safety of Britannia aircraft, their successful diagnosis and comprehensive and effective follow-up action. These included the development of a Command modification to prevent the loss of life-raft panels, and another to modify the wheel-change jack which had been damaging the bogie beam on the undercarriage. He also carried out investigations into the source of contamination in booster-pump filters and corrected weaknesses in the lay-out of hydraulic pipelines which presented a serious fire risk and could have caused failures in the brake system. Although these investigations were only part of his normal task, he undertook them with meticulous thoroughness and determination.'

The 1968 Meteorology Prize was awarded to Mr A. H. Hooper, Senior Experimental Officer, Meteorological Office, with the following citation :

> 'In recognition of his work during the last four years on the development and trial of a new radiosonde system. The work demanded skills of a high order in the fields of electronic engineering, automatic data processing and upper air meteorology. Throughout the work Mr Hooper has shown tenacity and exceptional application in the face of many difficulties and setbacks, leading a small team very effectively by infecting them with his own enthusiasm. The result is that we now have a radiosonde which can be a world leader in performance. Its general adoption will lead to much better observations at much greater heights and enable the Meteorological Office to meet the demands of aviation for knowledge of conditions at such levels.'

The 1968 Meteorological Observers' Award was awarded to Mr W. J. Cox, Senior Scientific Assistant, Meteorological Office, with the following citation :

> 'In recognition of his pioneering work in the measurement of upper air temperatures and humidities from a merchant ship in the course of her normal voyages in the Atlantic and Indian Oceans. The leader of a team of two, Mr Cox demonstrated that it was possible to adhere to a scheduled routine in all weather experienced, which included gale force winds; the routine involved launching balloons and associated radiosonde equipment from an open deck, receiving data from the sonde and arranging for the timely despatch of the computed data to shore stations. His resourcefulness and infective enthusiasm has enabled the Meteorological Office to plan realistically to extend the operation to ten merchant ships in the coming four years as part of the United Kingdom contribution to the World Weather Watch under which aviation and other interests should benefit materially.'

The Second Memorial Award for 1968 was awarded to Dr J. D. Woods, Principal Research Fellow, Meteorological Office, with the following citation :

> 'During the past three summers Dr J. D. Woods has organized and led expeditions which have used skin-diving techniques to study directly the upper layers of the sea. Undertaking much of the underwater

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PLATE III—AWARD WINNERS WITH MAJOR AND MRS K. J. GROVES AND AIR MARSHAL SIR PETER WYKEHAM

Left to right : Dr J. D. Woods, Mr A. H. Hooper, Mrs W. J. Cox, Mr A. M. Dunning, Major K. J. Groves, Flight Lieutenant J. F. Narramore, Mrs K. J. Groves and Air Marshal Sir Peter Wykenham (see page 60).

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PLATE IV—MAJOR K. J. GROVES WITH MR A. H. HOOPER, WINNER OF THE MEMORIAL PRIZE FOR METEOROLOGY

(See page 60.)

PLATE V—MAJOR K. J. GROVES WITH DR J. D. WOODS, WINNER OF THE SECOND MEMORIAL AWARD

(See page 60.)

observation himself, he has developed techniques for making the water movement visible by means of dye and designed new instrumentation for measuring temperature gradients.

His work has proved valuable not only for the new knowledge which has been acquired on the structure of the oceans and the transfer of heat between ocean and atmosphere, but as a stimulus to the theoretical understanding of stratified fluids in general and such related phenomena as clear air turbulence. Without Dr Woods' enterprise and initiative these underwater observations would not have been made.'

REVIEW

Formation of precipitation and modification of hail processes, by G. K. Sulakvelidze, N. Sh. Bibilashvili and V. F. Lapcheva. 250 mm × 180 mm, pp. v+208, *illus.* (translated from the Russian by the Israel Program for Scientific Translations, Jerusalem), Oldbourne Press, 1–5 Portpool Lane, London, E.C.1, 1967. Price: 99*s*.

Scientists at the High-Mountain Geophysical Institute (VGI) in the Soviet Union have recently developed a seeding technique by which they claim they can virtually eliminate damaging hail from seeded hailstorms. The present book, written by the chief scientists involved in the VGI hail suppression programme, describes both the seeding technique and its scientific basis. Although designed for the specialist reader, this book is likely to be widely read since it offers the first convincing evidence of successful hailstorm modification. Despite the absence of statistical significance tests, the authors make a strong case for the success of their technique; to quote them, 'it is difficult to consider a fortunate accident the cessation of hail fall in 60 experiments directly after the introduction of the seeding reagent into the cloud and precisely in the place where it was introduced. It is also hardly possible to consider as accidental the fact that during three years of work in the most hail-prone regions of the Soviet Union (the northern Caucasus) not a single case of hail fall on the protected territory was observed'.

The first three chapters of the book are concerned with the vertical velocity structure of convective clouds and with the growth of the cloud droplets and hailstones. In addition to surveying some basic Russian and English language literature, the authors present some important observations and ideas of their own in order to establish the hail-growth model which serves as the basis for their hail suppression work. Particularly important are their measurements of vertical velocity profiles within convective clouds using no-lift, balloon-borne, corner-reflectors tracked by radar. They report that, although the updraught in developing clouds fluctuates strongly with height, the updraughts in mature clouds tend to resemble a relatively steady jet, with vertical velocities typically reaching 20 to 25 m/s in the middle or upper parts of the cloud. Stimulated by these observations and by their earlier direct measurements of liquid water contents of 20 to 30 g/m^3 in mature convective clouds, the authors go on to suggest that the diminution in updraught velocity towards the top of convective clouds results in the gradual accumulation of high concentrations

of raindrops where the terminal fall-speed of the drops is comparable to the updraught velocity. They obtain an expression for the maximum attainable liquid water content in the so-called *accumulation zone* as a function of the vertical updraught profile, but their treatment is unrealistic in so far as it is one-dimensional and fails to take into account the decrease in the concentration of raindrops due to horizontal divergence above the updraught maximum. Nevertheless, as Professor K. Haman at the University of Warsaw has recently emphasized, it is still possible to account for the development of an accumulation zone in terms of the recycling of raindrops up and down around the level of maximum updraught velocity. In any case, regardless of how an accumulation zone is produced, the VGI scientists believe that such a zone should constitute a suitable environment for rapid hailstone growth provided that it is situated within the supercooled region. They propose a mechanism for hail production in which a few drops freeze spontaneously at the top of the accumulation zone (at a temperature between -15 and -22°C), and then grow very rapidly accreting supercooled drops as they fall down through the accumulation zone. Although heat budget considerations imply that hailstones grown in this manner will contain a high proportion of unfrozen water, the model does not explain how such hailstones are consolidated to enable them to survive melting during their final descent below the 0°C level. The probability of hail growth is assessed according to this model using thermodynamic 'slice' theory to predict the height and magnitude of the updraught maximum. If, for example, the updraught maximum is too low and the accumulation zone lies mainly below the 0°C level, then significant hail growth does not occur. The surprisingly good (90 per cent) accuracy of this method of hail forecasting in the northern Caucasus is given as evidence of the validity of the hail-growth model.

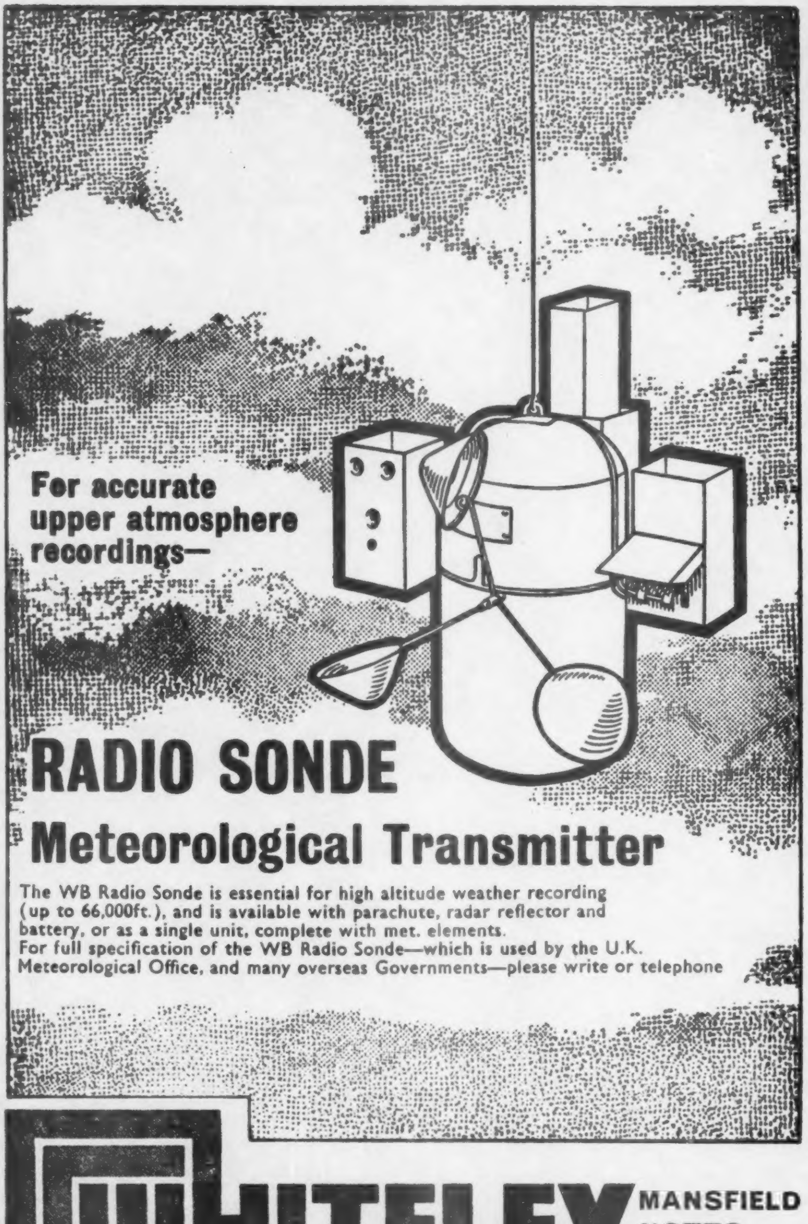
The fourth chapter discusses radar techniques used by the VGI workers for identifying hailstorms. Features such as the height of the echo top and the maximum radar reflectivity are used to determine whether or not hail is present within the cloud. The authors also suggest that it is possible to identify the accumulation zone as being associated with a reflectivity maximum aloft; however, they present no convincing evidence to support this claim. As far as the estimation of hail size within the cloud is concerned, the problem has always been that the back-scattering cross-section of hailstones whose diameter is comparable to the radar wavelength is a complex function of hail size, with stones of significantly different diameters sometimes displaying similar cross-sections. To circumvent this problem the VGI scientists use a two-wavelength radar approach in which they compare the reflectivities measured at 3- and 10-cm wavelength, assuming that the reflectivity is due to an exponential spectrum of hail sizes similar to that measured directly at the ground. Now this kind of approach was proposed in 1961 by Professors Atlas and Ludlam but it was not pursued in the West because its validity is not only influenced by changes in the shape of the hail size spectrum within the cloud, but is also influenced (i) by the dependence of the cross-section of hailstones upon their shape and liquid water content, and (ii) by the effect of the attenuation of radar energy at 3-cm wavelength by intervening precipitation. It is, therefore, interesting that this technique is apparently being applied with some success by the Soviet workers. They state, for example, that the mean error in the radar determination of hail size at the ground, allowing for melting below

the 0°C level, is as little as 35 per cent. By using a radar wavelength of 5 or 6 cm instead of the present heavily attenuated 3 cm, and by using in addition a third wavelength of about 20 cm, it should be possible to improve this accuracy significantly.

The fifth and final chapter in this book is devoted mainly to the VGI hail suppression technique itself. In essence this entails the dispersal of a seeding agent (PbI_2) into the accumulation zone at the -5°C level. The dispersal is carried out *directly into this zone* by means of artillery shells, since the authors believe that the seeding material becomes less effective as a nucleating agent if it first encounters water at temperatures above 0°C. The aim of the seeding is not to freeze all of the supercooled water in the accumulation zone but, rather, to increase the number of hail nuclei. The idea, as first proposed by Ludlam, is to increase the number of hail embryos competing for the available liquid water to the extent that none is able to grow large and most are able to melt completely before reaching the ground. Assuming a yield of 10^{14} nuclei per gramme of reagent and assuming that 1 in 10^4 of these produces a hail embryo, then about 10 g of reagent are required per 1 km^3 of air in order to promote sufficient competition to prevent the hailstone embryo from growing large. Such a dose needs to be repeated at intervals of 5 to 10 minutes so long as the hail cloud persists. The rate of propagation of the area of glaciation by seeding has been found to be as high as 10 to 20 m/s; possibly ice splinter multiplication processes are effective in accelerating the rate of glaciation. It is claimed that, not only does the hailfall at the surface cease soon after seeding, but also that the results of seeding can be observed by radar, for example, as a diminution of reflectivity in the seeded area. The range of a single anti-aircraft gun of the kind used to disperse the seeding agent is such as to permit an area of radius 10 km to be protected. The entire operation — consisting of the hail forecast using the 'slice' method, the identification of the hail-growth region by radars, the seeding by artillery shells, and finally the survey of the surface distribution of precipitation beneath the path of the seeded storm — is carried out like a well-planned military operation. One cannot fail, when reading this book, to be impressed by the all-round success claimed for all phases of the operation; however, this reviewer at least was worried by the feeling that things were sometimes almost, 'too good to be true'. Finally, although it seems reasonable to suppose that this study will serve as a blueprint for further hail suppression studies in other parts of the world, it is important to stress the need for more basic research into the structure of hailstorms, since it is by no means obvious that all hailstorms conform to the Rain-Storage Model proposed here.

This book is generally clearly written and well translated, although the reproduction of the photographs is poor and the mathematics in a few places is more detailed than need be. It is recommended reading for anyone with a specialist interest in precipitation physics or weather modification.

K. A. BROWNING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